UNITED STATES UTILITY PATENT APPLICATION

FOR

COLORATION INDICATIVE OF DRAFT ANGLES

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COLORATION INDICATIVE OF DRAFT ANGLES

TECHNICAL FIELD

The present invention relates to the field of computer aided design (CAD). More specifically, it relates to displaying of a modeled object with coloration indicative of draft angles of a pull direction at various locations of the modeled object.

BACKGROUND

Certain objects, such as plastics and metals, can be manufactured using a mold. For example, an object may be manufactured by injection molding. A mold is first created. Materials, typically in a substantially liquid and raised temperature form, are injected into the mold. When the materials are cooled and return to a solid form, the object may be removed from the mold.

Each mold typically includes multiple sections. The sections are designed to be able to removably mate with each other. Further, the molded object may be removed or "pulled away" from one or more of the mold sections. The direction in which each mold section is pulled away from the molded object from is referred to as the "pull direction".

FIG. 1A illustrates a simple sphere **110** and a mold section **120** of a mold employed in the creation of the sphere **110**. FIG. 1B illustrates an expanded view of a portion **140** of the mold/sphere interface. The draft angle **150** is defined as the

smaller angle between the surface of the sphere (more specifically the tangent **160** to the sphere) and the pull direction **130**. Further, typically, the reference coordinate system is "positioned" such that large positive values of the draft angles **150** denote relative ease in "pulling" the mold **120** away from the object **110**, draft angle values around 0 denote relative difficulty in "pulling" the mold **120** away from the object **110**, and large negative draft values denote virtual "impossibility" in "pulling" the mold **120** away from the object **110**. In fact, in the last case, the object **110** may be "pushed" into the mold **120**, as opposed to being "pulled" from the mold **120**. Thus, information about the draft angles of a pull direction at various locations of a molded object is useful to a designer.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be described referencing the accompanying drawings in which like references denote similar elements, and in which:

FIGs. 1A and 1B illustrate an object and a mold, including a draft angle relative to a pull direction at a location of the object.

Fig. 2 illustrates an overview of a number of embodiments of the present invention.

FIG. 3a illustrates a more detailed look at draft angles including their relationships to other geometric parameters.

FIG. 3b illustrates a color map in accordance with one embodiment.

FIG. 4 illustrates another embodiment of the present invention.

FIG. 5 illustrates a vector/matrix transformation for calculating a cosine of an angle between two vectors.

FIG. 6 illustrates utilizing matrix operations for calculating a correct texture map index, in accordance with one embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Embodiments of draft angles indication method and apparatus are described herein. In particular, embodiments employing coloration of a molded object to indicate draft angles of a pull direction at various locations of the molded object will be described. Further, embodiments employing a color map that is based on the trigonometric values (such as sine values) of the draft angles will be described, including embodiments that access the color map with the cosine of the "complementary" angles having corresponding right angle relationships with the draft angles.

In the following description, numerous specific details are set forth to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the embodiments being described.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features,

structures, or characteristics may be combined in any suitable manner in one or more embodiments.

To appreciate the present invention, first consider when displaying an object in a Computer Aided Design (CAD) system, if a pull direction is defined, it is beneficial to indicate the draft angles relative to the pull direction at various locations of the object by correspondingly coloring the object. For example, areas with locations having high positive draft angle values (easy to pull the mold away from the object) may be colored with a color at one end of the color spectrum, such as red, areas with locations having close to the draft angle value of zero (difficult to pull) may be colored with a color in the middle of the color spectrum, such as yellow, and areas with locations having high negative draft angle values (impossible to pull) may be colored with a color in the other end of the color spectrum, such as blue.

One possible approach to so color the object to indicate the draft angles relative to the pull direction at the various locations of the object is to calculate the appropriate color at each vertex of each triangle primitive of a mesh employed to model the object, based on the draft angle calculated at each vertex of each triangle primitive. The color to be displayed at other points within each triangle primitive are interpolated based on the colors calculated for the vertices.

However, experience had shown that the resulting color is generally crude, unless a very dense mesh having many more smaller triangle primitives is used. But, the employment of very dense mesh is not always practical, as the computations are

likely to be prohibitively intensive. In particular, the computations may be so intensive, rendering it virtually impossible, on even high performance computers, to respond and re-color a molded object in real time to reflect a user change of the pull direction.

Fig. 2 illustrates an overview of the present invention, in accordance with a number of embodiments. As illustrated, for these embodiments, computing environment **200** includes CAD application **202**. The computing environment may be a uni or multi-processor computer, a massively parallel computing system, or a cluster of locally or remotely networked computing devices.

CAD application **202**, as shown, is advantageously equipped with a coloration function **204** for coloring a modeled object to convey draft angles (θ) of a pull direction at the various locations of the modeled object. The modeled object may be any physical object of manufacture being modeled, e.g. a molded object.

Coloration function **204** is designed to effectuate the coloration through cooperation with graphics services **210**, and the employment of a color map **206**. In other words, coloration function **204** is designed to effectuate the coloration by providing necessary geometric parameter values to graphics services **210** to employ color map **206** to determine the colors for the pixels of the various locations of the modeled object.

In various embodiments, color map **206** advantageously specifies a spectrum of color, e.g. from blue to yellow to red, for various trigonometric values of the draft

angles (θ). In other words, color map **206** may be accessed to provide a color for one or more pixels of a surface location of an object, based on the trigonometric value of the draft angle (θ) of a pull direction at the surface location.

An example of color map **206** for 1024 pixels is illustrated in **Fig. 3b**. For the embodiment, color map **206** specifies a spectrum of color for various values of sin(θ), e.g. from –1 to 0 to 1. In alternate embodiments, color map **206** may be a larger map (e.g. for 2,048 pixels) or a smaller map (e.g. for 512 pixels). Color map **206** may also be based on other trigonometric values of draft angles (θ). In yet other embodiments, preferably, the color spectrum as well as the draft angle range of color map **206** may be configured by a user.

From the description to follow, the advantage flowing from the novel employment of a color map that is based on the trigonometric values of draft angles (θ) will be readily apparent to those of ordinary skill in the art.

Continuing to refer to **Fig. 2**, graphics services **210** are equipped to accept geometric parameter values of the various locations of the object from coloration function **204** to enable graphics services **210** to determine the trigonometric values of the draft angles (θ) of a pull direction at the various locations, for use to access color map **206** to determine the color values of the corresponding pixels of the various locations.

For example, for the earlier described color map **206** based on the sine values of draft angles (θ), coloration function **204** may provide the necessary geometric

parameter values of the various locations for graphics services **210** to determine the sine values. In various embodiments, as will be described in more details below, this is effectuated by coloration function **204** providing the necessary geometric parameter values of the various locations for graphics values **210** to determine the cosine values of the complementary angles having a right angle relationship with draft angles (θ).

Accordingly, during operation, when a need to color an object to indicate the draft angles of a pull direction at the various locations of an object arises, coloration function **204** invokes the services of graphics services **210**, providing graphics services **210** with the necessary parameter values to determine the trigonometric values for the various locations of the object, thereby allowing graphics services **210** to determine the appropriate color values for the pixels corresponding to the various locations of the object, using color map **206**.

Referring now to **FIG. 3a**, wherein a more detailed illustration of a couple of draft angles, including their relationships to other geometric parameters, is shown. As earlier described, draft angle Θ **270** is the smaller angle between the pull direction **230** and a surface tangent **260**. Three such draft angles are illustrated, with the draft angle on the right hand side of the figure (Position C) having a positive angle, the middle figure (Position B) having a draft angle value of about zero, and the draft angle on the left hand side of the figure (Position A) having a negative draft angle value.

Complementary angle Φ represents the angle between the pull direction **230** and the surface normal **280**. Accordingly, angles Φ and Θ have the relationship of

$$\Phi = 90 - \Theta$$

Thus, by virtue of the "right angle relationship", the values of sin(Θ) equal the values of cosine(Φ). In other words, the values of sin(Θ) may be computed by computing the values of cos(Φ).

Note that the surface normal **280** for each of the three vertices of a triangle are typically not the same, although a triangle is typically a planar figure. Thus, in one embodiment, the surface normals are not the normals to the triangle itself, but rather the normals at the vertex locations to the curved surface of which the triangle mesh is an approximation.

Still referring to **Fig. 3a**, cos(Φ) may be computed by computing

$$\cos(\Phi) = \frac{N \bullet P}{|N||P|}$$

where N and P are the normal and pull direction vectors respectively, and $N \bullet P$ is the inner product of the N and P vectors.

If *N* and *P* are both normalized, then cos(Φ) may be computed by simply computing

$$\cos(\Phi) = N \bullet P = Nx \bullet Px + Ny \bullet Py + Nz \bullet Pz$$

where N_x, N_y, N_z and P_x, P_y, P_z are components of N and P respectively.

Fig. 4 illustrates another embodiment of the present invention that is based on a color map specifying color values in term of values of sin(Θ), and leverages on the fact that sin(Θ) may be calculated by calculating cos(Φ) = $N \bullet P = Nx \bullet Px + Ny \bullet Py + Nz \bullet Pz$. As illustrated, embodiment **300** (hereinafter, may also be referred as system **300**) includes processor **310**, memory **320** and graphics hardware **330** coupled to each other as shown. Graphics hardware **330** includes in particular the hardware for calculating the texture data for texturing a surface (e.g. a marble surface, a wood surface, a leather surface and so forth). Further, the hardware to calculate the texture data includes the hardware that applies a texture map **328** to a set of surface coordinates, with the option of applying or not applying a transformation as part of the calculation of the texture data **350**. The transformation, if performed, is an inner product calculation between the surface coordinates and a transformation matrix (similar to the inner product operation that may be performed to obtain the values of cos(Φ)).

Memory **320** stores the earlier described CAD application **202** and coloration function **204** adapted to take advantage of the presence of graphics hardware **320**. Further, stored in memory **320** is the corresponding device driver **326** of graphics hardware **320**. For the embodiment, graphics device driver **326** includes an API **322** having a texturing function **324** that allows an application to texture a surface by

invoking texture function **324**, supplying the coordinates of the surface, a transformation matrix, if applicable, and a pointer to the texture map **328**.

In response, graphics device driver **326** causes the texture data **350** to be calculated employing graphics hardware **330**.

Thus, for the embodiment, when a need arises to color an object to indicate the draft angles of the various locations of the object, coloration function **204**, initializes the "texture map" with an embodiment of the above described color map, more specifically, a color map based on the sine values of draft angles (θ). Next, coloration function **204** invokes the texture function **324** with the normal components (N_x, N_y, N_z) of the various locations as the "texture coordinates of the surface to be textured", and the pull direction components (P_x, P_y, P_z) as values of the transformation matrix.

FIG. 5 illustrates the use of a transformation matrix for calculating a cosine of an angle between two vectors. A transformation matrix **510** is populated with a pull direction vector comprised of normalized pull direction components (P_x, P_y, P_z). A vector **520** is populated with the normalized normal components (N_x, N_y, N_z). The multiplication of the vector **520** and matrix **510** produces a vector **530** that contains, as an element, the same result as an inner product of the normal and pull direction vectors as described above. Thus, by populating a transformation matrix M with a pull direction unit vector, and providing a surface normal vector for a mesh vertex, a computing environment can be utilized to calculate the cosine for each mesh vertex's

surface normal vector, relative to the pull direction. This, in turn, provides the sine of the angle between the pull direction and the surface tangent as previous discussed.

The texture map used may be a one-dimensional texture map and thus the texture coordinates for a corresponding texture map have an index of 0 - 1. However, the range of the cosine value we obtain from the inner product calculation will be in the range –1 to 1. Thus, to convert between the inner product calculation and the texture map index, the inner product value needs to be reduced by ½ and the result shifted by ½. E.g. we would like to map P • N having a [-1...1] domain to a [0...1] domain. Thus, ½ (P • N) will generate the reduced cosine value. A ½ can be added to generate the necessary shift. Thus, ½(P • N) + ½ will generate the proper texture coordinate, in the range [0...1], for the texture map.

FIG. 6 illustrates utilizing matrix operations for calculating a correct texture map index, in accordance with one embodiment. Utilizing a four dimensional array, the scaling and shifting of the above operation can be performed at the time of the calculation of the inner product value. When the transformation matrix is populated with the value of the normalized pull direction components (P_x, P_y, P_z) **605**, the values are scaled (e.g. multiplied by ½) **610** prior to being send to the transformation matrix. These values provide the scaling in the inner product calculation as discussed above. A vector **620** is populated with the normalized normal components (N_x, N_y, N_z). The fourth dimension of the vector **625** and the first row of the transformation matrix **615** is populated with constants to provide the shifting

component of the calculation. The first term **630** in the resulting matrix provides us with a term of interest. The result:

$$P_x N_x / 2 + P_x N_x / 2 + P_x N_x / 2 + 1/2$$

provides us with a scalar that is identical to our desired scaled and shifted value for indexing into the color map:

$$\tfrac{1}{2}(P_x N_x + P_x N_x + P_x N_x) + \tfrac{1}{2}$$

$$\tfrac{1}{2}(\mathrm{P} \bullet \mathrm{N}) + \tfrac{1}{2}$$

Thus, utilizing matrix operations available in a computing environment, the scaled and shifted inner product, representative of the draft angle, may be calculated.

Accordingly, device driver **326** causes "texture data" to be computed employing graphics hardware **330**. However, by virtue of the data being initialized as the "texture map", and the data being supplied as the "texture coordinates" and the "transformation matrix", the resulting "texture data" are in substance the pixel color data for coloring the various locations of the object to indicate the draft angles (θ) of a pull direction at the various locations of an object.

In other words, graphics hardware **330** together with its device driver **326** (including its API **322**) is substantially a hardware/software embodiment of graphics services **210** of **Fig. 2**.

Since graphics hardware **330** can perform these computation rapidly. The embodiment is particularly suitable to support real time re-computations of the pixel color values, in response to a user making changes to the pull direction.

Furthermore, for a mesh of a given fineness, the resulting coloration is much more accurate than what can be achieved by interpolating colors assigned to the various mesh vertices, as described earlier (page 6). Using the present method, the colors displayed at pixels within a single mesh triangle can exhibit all the color transitions required to portray the change in draft angle across that triangle, which simple color interpolation cannot do. This is because the color map is itself treated as a texture image which is mapped to the triangles comprising the surface mesh just as a texture of a physical material would be in other uses of texturing.

Processor **310**, memory **320**, as well as graphics hardware **320** (notwithstanding the above described requirements) represent a broad range of these elements.

Of course, in alternate embodiments, dedicated hardware substantially equivalent to the hardware provided for performing the texture data calculation may be provided to perform the pixel color value calculation directly, without having to leverage on the hardware provided for performing texture data calculation as described.

As can be seen from the above description, a novel method and apparatus for providing coloration indicative of draft angles is disclosed. The above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. These modifications can be made to the invention in light of the above description.